IN SITU CONTROL OF THE GE(100) SURFACE DOMAIN STRUCTURE FOR III-V MULTI-JUNCTION SOLAR CELLS

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1. Introduction

Vicinal Ge(100) is the common substrate for state of the art multi-junction solar cells grown by metal-organic vapor phase epitaxy (MOVPE). While triple junction solar cells based on Ge(100) present efficiencies > 40%, little is known about the microscopic III-V/Ge(100) nucleation and its interface formation. A suitable Ge(100) surface preparation prior to heteroepitaxy is crucial to achieve low defect densities in the III-V epilayers. Formation of single domain surfaces with double layer steps is required to avoid anti-phase domains in the III-V films. The step formation processes in MOVPE environment strongly depends on the major process parameters such as substrate temperature, H_2 partial pressure, group V precursors [1], and reactor conditions. Detailed investigation of these processes on the Ge(100) surface by ultrahigh vacuum (UHV) based standard surface science tools are complicated due to the presence of H_2 process gas. However, in situ surface characterization by reflection anisotropy spectroscopy (RAS) allowed us to study the MOVPE preparation of Ge(100) surfaces directly in dependence on the relevant process parameters [2, 3, 4]. A contamination free MOVPE to UHV transfer system [5] enabled correlation of the RA spectra to results from UHV-based surface science tools.

In this paper, we established the characteristic RA spectra of vicinal Ge(100) surfaces terminated with monohydrides, arsenic and phosphorous. RAS enabled in situ control of oxide removal, H_2 interaction and domain formation during MOVPE preparation.

2. Results

X-ray photoemission spectroscopy (XPS) measurements confirmed oxide and carbon removal from Ge(100) substrates by H_2 annealing in MOVPE ambient. The vicinal substrates exhibit a (2x1) majority domain and mainly D_B-type double layer steps according to low energy electron diffraction (LEED) measurements (Figure 1 inset) and scanning tunneling microscopy (STM). The Ge(100) RA spectra after H_2 annealing deviate from reference data of clean surfaces prepared in UHV [6] (Figure 1), due to the presence of hydrogen bonds. This is in agreement with FTIR measurements which confirmed a monohydride termination of the Ge(100) surface. RAS measurements enabled in situ observation of hydrogen desorption and adsorption in dependence of process temperature and process gas (H_2, N_2).

We observed a characteristic change of the in situ RA spectra of vicinal Ge(100) substrates, when arsenic is supplied during annealing either by tertiarybutylarsine or by background arsenic (Figure 2(a)). The associated LEED patterns showed almost single domain (2x1) and (1x2) reconstructions, respectively. However, STM (Figures 2(b) and (c) revealed distinct differences in the step structure and XPS indicated differences in the As coverage of the Ge(100):As samples. We conclude that both the As dimers and the step structure contribute to the RA spectra of vicinal Ge(100):As surfaces. The sensitivity to As dimer orientation enables precise in situ control over preparation of single domain Ge(100):As surfaces.

3. Figures

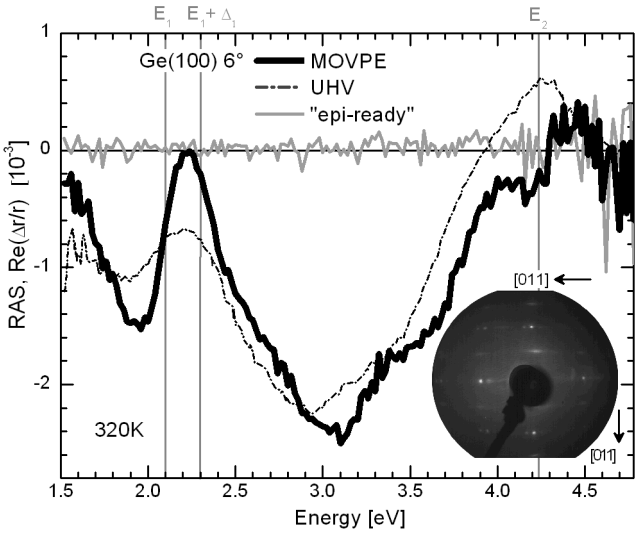
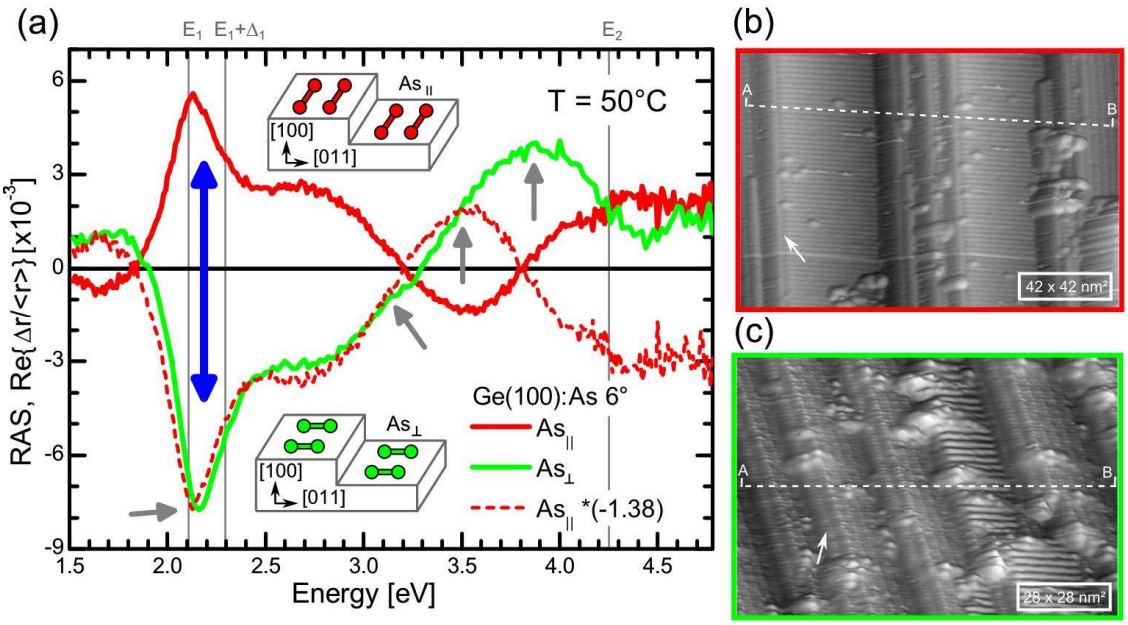


Figure 1. In situ RA spectra of "epiready" (grey) and H_2 annealed (black) Ge(100) with 6° miscut in [011] measured at 320 K in H_2 ambient, and RAS of UHV prepared Ge(100) (dash-dotted) [6]. The LEED pattern corresponds to the H_2 annealed Ge(100) sample.



Figures 2(a)-(c). In situ RAS and STM of Ge(100):As 6° with predominant (2x1) (red line) and (1x2) (green) surface reconstruction.

References

[1] W.E. McMahon and J.M. Olson, Phys. Rev. B 60, 15999 (1999).

[2] S.Brückner, et al., Phys. Stat. Sol. (RRL) 6, 178–180 (2012).

[3] S.Brückner et al., Appl. Phys. Lett. 101, 121602–121602–4 (2012).

[4] E. Barrigón et al., J. Cryst. Growth (2012), in press.

[5] T. Hannappel, et al., Rev. Sci. Instrum. 75, 1297 (2004).

[6] U. Rossow, et al., J. Vac. Sci. Technol. B 18, 2229 (2000).